NISTIR 6890

Fire Resistance Determination and Performance Prediction Research Needs Workshop: Proceedings

William Grosshandler
Editor

National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

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Donald L. Evans, Secretary

Technology Administration
Phillip J. Bond, Under Secretary of Commerce for Technology

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Arden L. Bement, Jr., Director

P. Parallels Between Performance-based Engineering for Fire and Earthquake Hazards
Greg Deierlein, Department of Civil and Environmental Engineering
Stanford University, Stanford CA

Parallels Between Performance-Based Engineering for Fire and Earthquake Hazards

Greg Deierlein
Stanford University & PEER

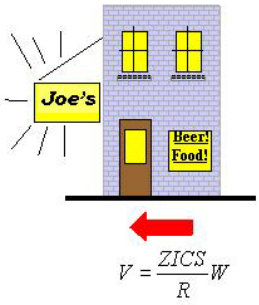
NIST – Research Needs for Fire Resistance Determination and Performance Prediction
Feb. 19-20, 2002

Final Draft ICC Performance Code (ICC 2000).

Objective: To limit the impact of a fire event on the building, its occupants, processes and use; and to limit the impact of an exposing fire on buildings, adjacent properties and processes.

	PERFORMANCE GROUPS			
	I	II	III	IV
Very Large (Very Rare)	SEVERE	SEVERE	HIGH	MODERATE
Large (Rare)	SEVERE	HIGH	MODERATE	MILD
Medium (Less Frequent)	HIGH	MODERATE	MILD	MILD
Small (Frequent)	MODERATE	MILD	MILD	MILD

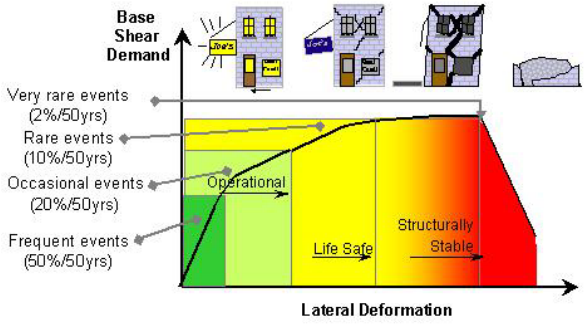
Traditional Earthquake Engrg. Approach



$$V = \frac{ZICS}{R}W$$

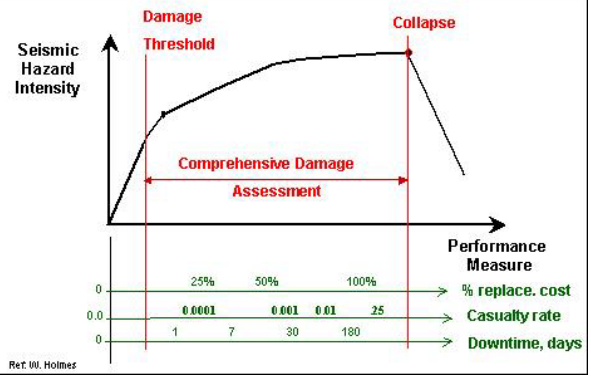
- Linear analysis model
- Simplified design base shear
- Prescriptive details
- Uncertain outcomes
- Owners informed of code conformance, but not building performance

FEMA 273/356 Performance Assessment



Ref. R.O.Hamburger

More Explicit Performance Assessment

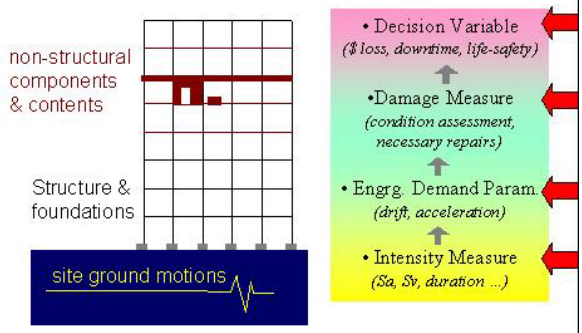


Ref. W. Holmes

Key Attributes of Performance Based Approaches

- More Scientific & Transparent
- Address Stakeholder Decision Needs
  - multi-level decision-oriented performance objectives
- Consistent treatment of risk and uncertainties

PBEE Methodology Components



PBEE – Probability Framework Equation

$$\nu(DV) = \iiint G(DV \mid DM) \mid dG(DM \mid EDP) \mid dG(EDP \mid IM) \mid d\lambda(IM)$$

Impact | Performance (Loss) Models and Simulation | Hazard

IM – Intensity Measure

EDP – Engineering Demand Parameter

DM –

DV –

ν(DV) – Prob… …riable

(e.g., Mean A…

Mean Annual … …ent Cost, etc)

Implementation Through LRFD-like Format:

$$\gamma_{D|S_a} \cdot \hat{D}_{S_a^{Pf_0}} \le \phi_C \cdot \hat{C}$$

Hazard Intensity Measure (IM)

Current Practice: Spectral Acceleration $S_a(T_1)$

USGS Hazard Curves

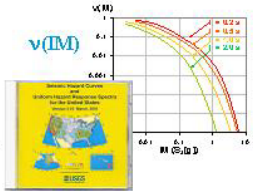
Mapped Fault Locations

Likelihood of Fault Rupture (rupture size and location)

Probabilistic Magnitude Prediction (M)

Distance (R) to Site

Attenuation Relationships: Sa (T) = fcn (M, R, T, soil, …)

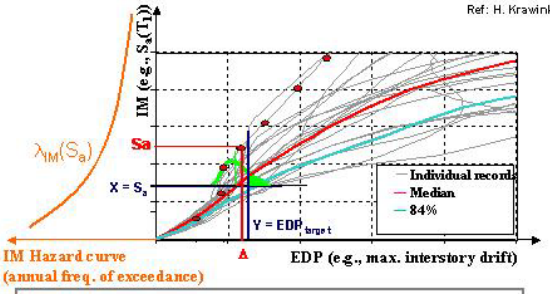


Static Analysis: $V \propto S_a(T_1)$

Dynamic Analysis: scale records to $S_a(T_1)$?

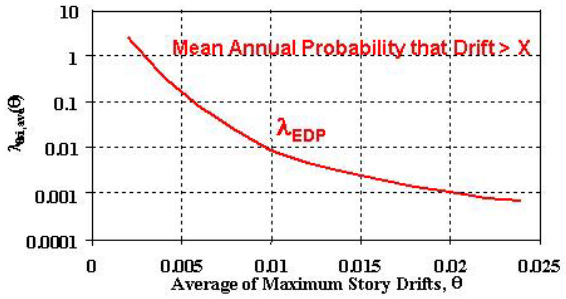
IM to EDP via "Incremented Dynamic Analysis"

Ref: H. Krawinkler



$$\lambda_{EDP}(y) = \int P[EDP \ge y \mid IM = x] \mid d\lambda_{IM}(x) \mid$$

EDP Hazard Curve (Interstory Drift)



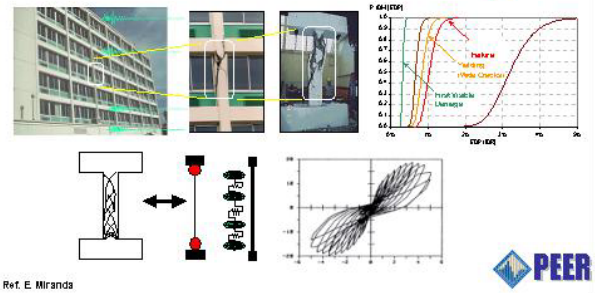
Ref: H. Krawinkler

Damage Measures

- **EDP ⇨ Physical Condition ⇨ Consequences**
- **Physical Condition**
  - cracking spalling, rebar buckling, …
  - component failure, tipping, …
- **Consequences**
  - repair measures (minor to major replacement)
  - life safety issues (e.g.,chemical release, falling hazards, etc.)
  - functionality (e.g., bridge alignment)

Damage Measure of Structural Components

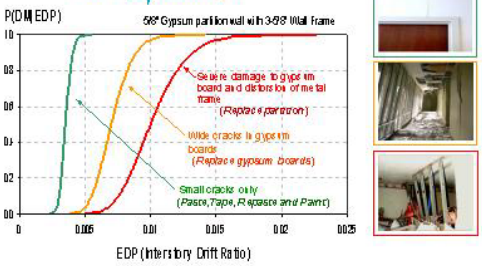
Fragility Functions
EDP ➡ DM



Ref. E. Miranda

DM of Nonstructural Components

Fragility Functions
EDP ➡ Damage



Ref: E. Miranda

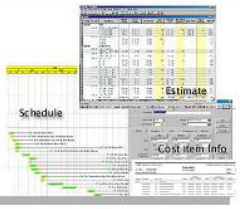
Performance Assessment & Decision Making

Damage to Decision Variables:

Casualty Rates (Risk of Injury)

Direct $ Loss (Repairs & Content Loss)

Schedule ➡ Downtime ➡ Indirect Loss



Decision Process:

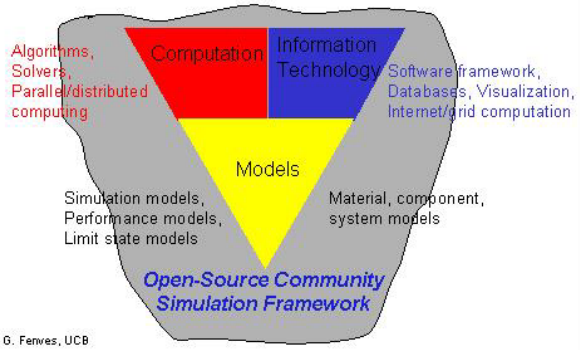
Economic Modeling (e.g., Benefit-Cost Analysis)

Societal – Political Expectations and Constraints

Risk Management (risk aversion, insurance vs. mitigation, ...)

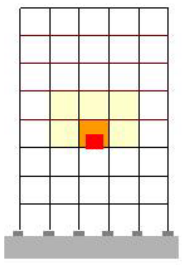
Decision Arena (single facility, multiple facilities, large inventory)

OpenSees – Integrated Simulation Platform



G. Fenves, UCB

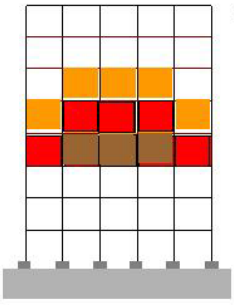
PBFE Methodology Components



- Decision Variable
  ($ loss, downtime, life-safety)
- Damage Measure
  (condition assessment, necessary repairs)
- Engrg. Demand Param.
  (temperature?, deflections?)
- Intensity Measure
  (Fire Load? Compartment temperature? Material Temperature?

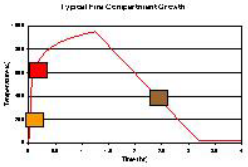
Question: *Who is the methodology geared toward - fire modeler, structural engineer, mechanical engineer ?*

Fire Performance Simulation



Fire Scenario & Time History Analysis:

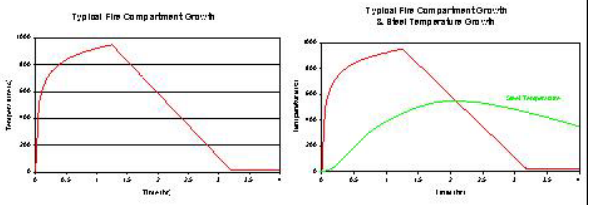
- **compartment fire curve (Temp. & Time)**
- **spatial distribution (spreading)**
- **temperature of structural members**



Question: *How to describe each scenario? How many scenarios? How severe?*

Intensity Measure?

- Fire Load, Ignition, Growth Parameters?
  - Fuel load, ventilation, compartment size, …
- Compartment Temperature (fire curve)?
- Steel Temperature ?



Engineering Demand Parameters?

- Global Deflections (sag, drift, …)
- Local Deformations (hinge rotations, strains,…)
- Component Forces
- "Hidden" effects (residual stresses, loss of material integrity, etc.)

BRE Website, 2001

Structural Simulation (IM to EDP)

- Material and Geometric NL Response
  - member and frame stability
- Temperature Loading Input
  - temporal and spatial
- Temperature Effects
  - thermal expansion
  - material degradation (Fy, E, other …)

Question: *How faithfully can (must?) global analysis model localized degradation (members, connections, composite action, …)*

Damage Measures

- Safety - Collapse or Partial Collapse
- Repair – member distortion, out of plumb, deck debonding, other loss in strength/stiffness

SCI Investigation of Broadgate Phase 8 Fire, 1991

Decision Variables

- Casualties (injury or death)
  - building inhabitants
  - emergency responders
- Repair Costs
  - contents, nonstructural, structural
  - correlations (water/smoke damage, burning, collapse)
- Downtime (repair time)

Big Issue: *Risk tolerance (earthquake versus fire)*

Issues: *Minimum protection and benefits of higher performance levels*

Issues and Needs

- Comprehensive Methodology
  - consistency with other hazards (earthquake, wind, …)
  - consistent with evolving code provisions (e.g., stability)
- Probabilistic Fire Hazard Assessment
  - or scenario (worst case) fire?
- Codification of Acceptance Criteria
  - explicit Decision Variables (casualty, $, downtime rates)
  - component strength checks (calibrated)
  - survival duration
- Structural Simulation Tools
- Validation (lab tests and field reconnaissance)